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Substitute Specification & Abstract
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OPTICAL ATTENUATOR

TECHNICAL FIELD

The present invention relates to an optical attenuator and more specifically to an optical attenuator used for attenuating optical signals in the fields of optical communications, optical measurements, CATV systems and the like.

BACKGROUND OF THE INVENTION

Optical attenuators comprising an optical fiber containing an optical attenuating dopant have been widely known. However, the dopant contained in these generally known optical attenuators has a transmitted light attenuating characteristic where the attenuation varies depending on the wavelength of the optical signal, i.e., it has a wavelength dependency. There is also known an optical attenuator in which the wavelength dependency is reduced by adjusting the mode field diameter of the optical fiber and by limiting the dopant area with respect to the mode field diameter in order to obtain almost equal attenuation of input optical signals of different wavelengths, e.g., 1.3 μm (short wavelength) and 1.5 μm (long wavelength) (Japanese Laid-Open ("Kokai") Nos. Hei. 8-136736 and Hei. 8-136737).

Recent diversification of optical communications, has created a demand for an optical attenuator having equal optical attenuation (eliminating the wavelength dependency) even in a

narrow wavelength range of 1300 mm ± 50 nm or 1550 ± 50 nm, for example or an optical attenuator whose wavelength dependency in optical attenuation is increased for optical signals of, for example, two different wavelengths of 1.3 μm (short wavelength) and 1.5 μm (long wavelength).

However, although the optical attenuators disclosed in Japanese Laid-Open ("Kokai") Nos. Hei. 8-136736 and Hei. 8-136737 are effective because they give almost equal attenuation of optical signals of two different wavelengths of 1.3 μm (short wavelength) and 1.5 μm (long wavelength), they have the problem that they are unable to provide equal optical attenuation (wavelength dependency is large) merely by limiting the dopant area or by adjusting the mode field diameter when the difference of the wavelengths is small.

When the optical signals of two different wavelengths of (short and long) wavelengths are input, it is theoretically possible to increase the wavelength dependency of the optical attenuation by using a dopant which gives greater attenuation of the short wavelength optical signals, with high concentration close to the axial core when the mode field is seen as a transverse section of the optical fiber or by using a dopant which gives greater attenuation of longwave optical signals with higher concentration close to the outer periphery of the optical fiber when the mode field is seen as a transverse section of the optical fiber (Japanese Laid-Open ("Kokai") No. Hei. 8-136736).

It is also theoretically possible to realize the equality (Japanese Laid-Open ("Kokai") No. Hei. 8-136737) by reversing the combination of the wavelength characteristics of the mode field diameter and the wavelength characteristics of the dopant.

However, although the difference between the short wavelength and the long wavelength attenuation is increased by raising the dopant concentration and by limiting the doping area to a narrow range with respect to the mode field diameter, there has been a difficult problem that, because the doping concentration of the dopant which can be contained in the optical fiber is limited, it is not possible to create an optical fiber product having characteristics which are stable when the concentration is too high and it is not technologically possible to create optical fiber products whose doping area is very narrow.

SUMMARY OF THE INVENTION

The present invention has been devised in view of the above-described problems and has as its object, firstly, to provide an optical attenuator which can equalize optical attenuation of optical signals having different wavelengths which are very close and, secondly, to provide an optical attenuator which can maximize the difference of optical attenuation of the optical signals having different wavelengths in an optical fiber with stable characteristics and wherein the dopant concentration and doping area range may be realized with a relatively low dopant concentration.

In order to achieve the above-mentioned objects, the present invention provides a single mode optical fiber, as an inventive optical attenuator, having a core with a refractive index of a center portion greater than that of a peripheral portion.

The wavelength dependency of the attenuation of transmitted light caused by the size of the mode field diameter is increased by adopting, as a distribution of the refractive index of the core, a distribution gradient selected from the group consisting of a gradient wherein the refractive index rises continuously from the peripheral portion to the center portion ("graded-index type"), a parabolic shaped gradient, a triangular wave shaped gradient, a square wave shaped gradient and a trapezoidal wave shaped gradient.

By constructing the optical attenuator as described above, it is possible to widen the limited width of the dopant area for obtaining the required attenuating characteristics as much as possible and to minimize the dopant concentration.

In one embodiment the optical attenuator contains dopant which provides greater attenuation of longer wave length transmitted light in a signal mode optical fiber and is constructed so that the dopant area is limited to the center part of the core and so that the refractive index at the center part of the core is greater than that of the peripheral part of the core. The wavelength dependency of the attenuation of transmitted light caused by the size of the mode field diameter is increased by adopting, as the distribution of refractive index of the dopant area,

a gradient selected from the group consisting of a gradient wherein the refractive index rises continuously from the peripheral portion to the center portion ("graded-index type"), a parabolic shaped gradient, a triangular wave shaped gradient, a square wave shaped gradient and a trapezoidal wave shaped gradient. By constructing the optical attenuator in this manner, it is possible to obtain equal attenuation of two input optical signals having different wavelengths which are short and whose difference is small (1300 nm ± 50 nm).

In another embodiment the optical attenuator is a signal mode optical fiber containing dopant which provides greater attenuation of shorter wavelength transmitted light and constructed so that the dopant area is limited to the peripheral part of the core and so that the refractive index at the center part of the core containing no dopant is greater than that of the peripheral part of the core. In this embodiment also, the wavelength dependency of the attenuation of transmitted light caused by the size of the mode field diameter is increased by adopting a refractive index gradient selected from the group consisting of a gradient wherein the refractive index rises continuously from the peripheral portion to the center portion, a parabolic shaped gradient, a triangular wave shaped gradient, a square wave shaped gradient and a trapezoidal wave shaped gradient, as the refractive index profile at the center part of the core where no dopant is contained. By constructing the optical attenuator in this manner, it is possible to obtain equal attenuation of two kinds of input optical signals having different long wavelengths whose difference is small (1550 nm ± 50 nm).

In still another embodiment an optical attenuator is a signal mode optical fiber containing a dopant which preferentially attenuates shorter wavelength transmitted light and is constructed so that the dopant area is limited to the center part of the core and so that the refractive index at the center part of the core containing dopant is greater than that of the peripheral part of the core. In this case, the wavelength dependency of the attenuation of transmitted light caused by the size of the mode field diameter is increased by adopting a refractive index profile selected from the group consisting of a gradient wherein the refractive index rises continuously from the peripheral portion to the center portion, a parabolic shaped gradient, a triangular wave shaped gradient, a square wave shaped gradient and a trapezoidal wave shaped gradient. By constructing the optical attenuator in the above manner, it is possible to obtain optical signals of two different wavelengths whose difference in attenuation of transmitted light caused by the difference of the wavelengths is maximized.

Another embodiment provides an optical attenuator in the form of a signal mode optical fiber containing dopant which gives greater attenuation of longer wavelength transmitted light and constructed so that the dopant area is limited to the peripheral part of the core. A gradient wherein the refractive index rises continuously from the peripheral portion to the center portion ("graded-index type") is adopted as the refractive index profile of the dopant area to increase the wavelength dependency of attenuation of transmitted light caused by the size of the mode field diameter.

In yet another embodiment an optical attenuator is constructed as a single mode optical fiber having a refractive index at the center part of the core greater than that of the peripheral part of the core due to incorporation of a dopant whose transmitted light attenuating characteristics depend on the wavelength of optical signal input to the optical fiber. The dopant concentration of the dopant area of the single mode optical fiber is distributed non-uniformly to provide a mode field which substantially contributes to the transmission of optical signals in the radial direction, i.e., transverse of the optical fiber. In this case, the wavelength dependency of the attenuation of transmitted light caused by the size of the mode field diameter is increased by adopting, as the distribution of refractive index of the dopant area, a gradient selected from the group consisting of a gradient wherein the refractive index rises continuously from the peripheral portion to the center portion, a parabolic shaped gradient, a triangular wave shaped gradient, a square wave shaped gradient and a trapezoidal wave shaped gradient. By constructing the optical attenuator in this manner, it is possible to obtain the required attenuating characteristics even when the dopant area is small and the dopant concentration is low.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows the structure of one embodiment of an optical attenuator according to the present invention, wherein the upper part of the figure shows an end face of the optical attenuator and the lower part shows a refractive index profile thereof.

FIG. 2 shows the optical attenuator of the present invention disposed at the center of a ferrule.

FIGs. 3a and 3b are graphs showing the relationship between wavelength and loss using various dopants.

FIG. 4 is a graph showing the optical signal power distribution within the optical attenuator of the present invention.

FIG. 5 is a graph showing the relationship between the ratio of difference of refractive index $\Delta 1/\Delta 2$, where $\Delta 1$ is the difference between the maximum refractive index of an axial center portion of the core and the refractive index in the cladding of the optical attenuator and $\Delta 2$ is the difference between the maximum refractive index in the outer peripheral portion of the core and the refractive index of the cladding, and the difference of loss at 1.50 μm and 1.60 μm.

FIG. 6 is a graph showing the attenuation with respect to wavelength when cobalt (Co) is doped in the center portion of the core of the optical attenuator.

FIG. 7 shows the structure of another embodiment of the optical attenuator of the present invention, wherein the upper part of the figure shows an end face of the optical attenuator and the lower part shows the refractive index profile.

FIG. 8 is a graph showing the attenuation with respect to wavelength when samarium Sm is doped in the whole core and samarium Sm is doped only in an axial portion of the core.

FIG. 9 is a graph showing the attenuation with respect to wavelength when cobalt (Co) is doped in the whole core and cobalt (Co) is doped only in the outer peripheral of the core.

BRIEF DESCRIPTION OF REFERENCE NUMERALS

5, 5' Single Mode Optical Fiber

6, 6' Core

6a, 6a' Center Portion of Core

(Portion close to the core axis)

6b, 6b' Outer Periphery portion of Core

(Portion close to the outer periphery of core)

7, 7' Dopant Area

9, 9' Mode Field

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of an inventive optical attenuator will be explained below with reference to the drawings.

Fig. 1 is a section view showing the structure of an optical fiber 5 which is used by disposition at the center of a ferrule 2 as shown in Fig. 2, for example. That is, in use it receives an optical signal at one end thereof and it outputs the signal from the other end after attenuating the optical signal by a certain degree. To this end a dopant for attenuating the optical signal is incorporated into the optical fiber 5.

In this embodiment, a graded-index type (its refractive index increases continuously from the outer peripheral part to the center part) is adopted as a refractive index profile at the center portion 6a close to the axis of the core 6 and a high concentration of dopant is contained within this area 7. The dopant area 7 is hatched in the figure.

Because a core diameter $2a_2$ is very small in the single mode fiber, energy of the optical signal propagates centering on the core 6 while actually overflowing to a portion of the cladding 8 at the outer periphery of the core 6. The range in which the larger portion of the energy is contained is a mode field 9 portion which contributes substantially to the transmission of the optical signals and may be found qualitatively by using Equation 1, as explained later for both the step-index type fiber and the graded-index type fiber. In the optical fiber 5 shown in Fig. 1, the diameter of the mode field 9 is denoted as 2o,, the diameter of the dopant area 7 as $2a_1$ and the diameter of the core 6 as $2a_2$. The difference between the maximum refractive index around the axial portion of the core 6 and the refractive index of the cladding is denoted as $\Delta 2$ and the difference between the maximum refractive index of the outer peripheral portion 6b of the core 6 and the refractive index of the cladding 8 as $\Delta 1$.

Use of dopants in the optical fiber 5 to attenuate the optical signals will now be explained. FIGs. 3a and 3b are graphs showing the relationship between wavelength and loss for various dopants. The horizontal axis of the graph represents the wavelength in nanometers (nm) and the vertical axis represents the optical attenuation in (dB/km). A transition metal or rare-

earth metal dopant is normally used for optical fibers used in communications. They may be used singly or in combinations of two or more. In Fig. 3a, (1) denotes the characteristics of manganese (Mn), (2) nickel (Ni), (3) chrome (Cr), (4) vanadium V, (5) cobalt (Co), (6) iron (Fe), and (7) copper (Cu). In Fig. 3b, (8) represents the characteristics of samarium (Sm) and (9) thulium (Tm).

The first embodiment of the optical attenuator of the present invention uses a dopant which attenuates more transmitted light when the wavelength of the optical signal is longer. When the wavelength to be used in this optical attenuator is around 1.5 pm to 1.6 pm for example, as can be seen from Fig. 3a, cobalt (Co) is suitable as the dopant.

Fig. 4 shows the optical signal power distribution when cobalt (Co) is used as the dopant and the dopant is contained in the area as shown in Fig. 1. The vertical axis of Fig. 4 represents the output power and the horizontal axis represents the position in the fiber in the radial direction. K1 in Fig. 4 is power distribution in the radial direction when an optical signal a wavelength of 1.5 μm is transmitted through the optical fiber. A curve K2 represents the power distribution of an optical signal of 1.6 μm.

Table 1 shows the difference of mode field diameter (hereinafter referred to as "MFD") corresponding to the respective wavelengths $\lambda 1$ and $\lambda 2$ in each fiber when the respective wavelengths $\lambda 1 = 1.50\ \mu$ m and $\lambda 2 = 1.60\ \mu m$ are inputted to the fiber having the structure of the first embodiment as shown in Fig. 4 and to the normal step index type fiber.

Table 1

	Difference (μm) of mode field diameter of 1.50 μm and 1.60 μm
First Embodiment	0.52
Step index	0.25

This shows that the difference of MFD of the fiber caused by the difference of wavelengths is large (wavelength dependency is large).

When cobalt (Co) is concentrated in the axial portion of the core, the longer the wavelength of a signal, the less the portion of the whole signal energy influenced by the attenuation becomes. This means that the wavelength dependency of the optical attenuation of the dopant is cancelled. As a result, the optical signals of short and long wavelengths, whose difference of wavelength is small, attenuate to the same degree in this attenuator as a whole.

In the case of the conventional step index type fiber, the concentration of dopant is high and causes a serious production problem when designed so as to show the same degree of attenuation as the first embodiment described above, because the dopant area of cobalt (Co) must be narrowed because the wavelength dependency of the optical attenuation of the MFD is small.

A concrete example using Equations 1 and 2 is given below. Equation1 is used for calculation of attenuation α of the optical fiber and Equation 2 is used for calculation of the mode field diameter ω.

Expression 1

Attenuation a	$\alpha = \frac{\int \alpha_{Co} A(r)P(r)rdr}{\int P(r)rdr}$ ... Equation 1 a: attenuation per 1 cm r: coordinate of fiber in radial direction A(r): concentration of Co in radial direction αCo: coefficient of absorbency of Co $\lambda = 1.50\ \mu m \rightarrow 5.19 \times 10^{-3}\ dB/cm \cdot ppm^{-1}$ $\lambda = 1.60\ \mu m \rightarrow 5.95 \times 10^{-3}\ dB/cm \cdot ppm^{-1}$ P(r): optical power distribution in radial direction
Mode Field Diameter ω	$2\omega = 2\left[\frac{2\int P^2(\mathbf{r})\mathbf{r}^3\mathbf{dr}}{\int P^2(r)rdr}\right]^{1/2}$ ... Equation 2 P(r): optical power distribution in radial direction r: coordinate of fiber in radial direction

As shown in Equation (1), the attenuation a of the optical signal in the optical fiber may be found from the power distribution P(r) of the optical signal in the radial direction and the distribution of concentration of cobalt, i.e., the dopant. The mode field diameter ω may be found from Equation (2).

The ratio (al/a2) of the area in which the graded-index type is adopted as the profile containing cobalt (Co) to the core diameter approaches the step index type when it is too large or too small and the wavelength dependency of the mode field diameter ω approaches the step index type. When the ratio (al/a2) is small, although the wavelength dependency of the attenuation α becomes small because the dopant area of cobalt (Co) becomes small, even when the wavelength dependency of the mode field diameter ω is small, there have been problems such as an increase of the amount of cobalt dopant and an increase of processing steps. Here, the result of using al/a2 = 0.5 is shown.

Fig. 5 is a graph representing the ratio of difference of refractive index $\Delta 1/\Delta 2$ (horizontal axis) and the difference of loss (attenuation) at 1.50 μm and 1.60 μm when the attenuation at 1.55 μm is 10 dB (vertical axis). It can be seen from Fig. 5 that the greater the ratio $\Delta 1/\Delta 2$, the wider the difference of the attenuation at 1.50 μm and 1.60 μm becomes. The wavelength dependency of attenuation of the dopant maybe canceled by this value.

Table 2 shows the structural characteristics of the fiber with $\Delta 1/\Delta 2 = 0.75$, whose wavelength dependency is small, as shown in Fig. 5. $\Delta 1/\Delta 2$ is not 0.35 because it represents a practical fiber structure in which bending loss and others are taken into account. .

Fig. 6 is a graph showing the attenuation with respect to the wavelength of the fiber in Table 2. The wavelength dependency is lessened by cobalt dopant in the center portion of the core of the optical attenuator and by adopting the graded-index type as the profile.

Table 2

	Core	a1/a2	$\Delta 1/\Delta 2$	MFD	MFD
	Diameter			(1.50 μm)	(1.60 μm)
Embodiment	7.4 μm	0.5	0.5	9.15	9.67
Step-Index	9.5 μm	0.5	0.5	9.26	9.51

This sample has been set so that the whole distribution of concentration of cobalt becomes fixed within the range in which cobalt (Co) is contained. The attenuation of the optical fiber has been set to 10 dB/m. As a result, $\Delta 1/\Delta 2 = 0.35$ and the wavelength dependency was eliminated when al/a2 = 0.5. A wavelength independent optical attenuator may be obtained by increasing $\Delta 1/\Delta 2$ when al/a2 becomes large and by decreasing $\Delta 1/\Delta 2$ when al/a2 becomes small.

The dopant which attenuates transmitted light more when the wavelength of the optical signal is longer is used in the center portion 6a of the core 6 of the optical fiber 5 in the first embodiment described above. In the alternative, dopant which attenuates transmitted light more when the wavelength of the optical signal is shorter may be used by changing the area where the dopant is doped. For instance, vanadium (V) of (4) and the like are shown in the example of Fig. 3a.

Fig. 7 shows a second embodiment of the inventive optical attenuator using a dopant which attenuates transmitted light more when the wavelength of the optical signal is shorter. In the second embodiment, a dopant-containing area 7' is created which preferentially attenuates shorter wavelength transmitted light more in a peripheral portion 6b of core 6' in which the refractive index profile is set as the graded-index type. In this case, the longer the wavelength of the optical signal whose power distribution extends in the radial direction of the optical fiber 5', the more it is influenced by the dopant.

Thus, the optical attenuation of the optical signal of wavelength within a certain range may be almost equalized by increasing the wavelength dependency of the mode fields 9 and 9', which substantially contribute to the transmission of optical signal of the single mode optical fiber, by controlling the refractive index profile, by selection of the distribution of concentration of dopant within the transverse section of the cores 6 and 6' of the optical fibers 5 and 5' and by using a dopant whose transmitted light attenuating characteristics depend on the wavelength of

the optical signal. It is noted that although the dopant is doped only to the axial portion 6a of the core 6 or in the peripheral portion 6b of the core 6 in the embodiments described above, it is possible to appropriately distribute concentration. Also, it is not necessary to obtain uniform characteristics for all wavelengths of optical signals and it is possible to set a concentration range so that a certain attenuation may be obtained for optical signals of several ranges.

The first and second embodiments provide almost the same attenuation to one having the small difference of wavelengths of optical signals of two different kinds of wavelengths to be inputted.

In a third embodiment of the optical attenuator of the present invention, the refractive index profile around the axial portion of the core of the single mode fiber is the same as that of the first and second embodiments described above. However, the third embodiment is different in that the wavelength dependency of the MFD. is increased by use of a dopant which attenuates transmitted light when the wavelength is short, e.g., samarium (Sm) shown by (8) in Fig. 3b, in the axial portion of the core and by adjusting the ratio between the diameter of the axially central portion of the core where the refractive index is set as the graded-index type and the core diameter.

Fig. 8 is a graph showing the attenuation with respect to wavelength when samarium (Sm) is doped in the whole core and when samarium (Sm) is doped only in the axially central portion of the core. It can be seen from the graph that the attenuation is greater when samarium is doped only in the axial portion of the core, i.e., between 1530 nm to 1550 nm.

The shorter the wavelength, the greater the optical signal is attenuated when two kinds of optical signals having different wavelengths are inputted. Further, a greater attenuation may be obtained without reducing the center core diameter more than required
and without increasing the dopant concentration.

Accordingly, this third embodiment is very effective in increasing the difference of attenuation of those two kinds of optical signals having different wavelengths.

In a fourth embodiment of the invention the refractive index profile around the axial core of the core of the single mode fiber is the same as those of the first and second embodiments described above. However, this forth embodiment is different in that the wavelength dependency of the MFD is increased by use of a dopant which attenuates transmitted light more when its wavelength is longer, e.g., cobalt (Co), in the portion of the core surrounding the axial center portion where the refractive index profile is set as the graded-index type and by adjusting the ratio of the diameter of the portion having a refractive index of the graded-index type (axial center portion) and the core diameter.

Fig. 9 is a graph showing the attenuation relative to wavelength when cobalt (Co) is doped throughout the whole core and when cobalt (Co) is doped only in an outer peripheral portion of the core. It can be seen from the figure that the attenuation wherein Co is doped only in the outer peripheral portion of the core is greater between 1560 nm to 1570 nm.

The longer the wavelength, the greater the optical signal is attenuated when two kinds of optical signals having different wavelengths are input. Further, a greater attenuation may be obtained without increasing the dopant concentration more than required.

Accordingly, this fourth embodiment is very effective in increasing the difference in attenuation of the two kinds of optical signals having different wavelengths.

As it is apparent from the above description, according to the present invention, it is possible to fix the optical attenuation for optical signals having different wavelengths which are very close with a practical doping range in which the dopant concentration is relatively low.

Further, according to the present invention, it is possible to increase the difference in optical attenuation as much as possible with a practical dopant concentration and a doping area range in which each characteristic of the optical fiber is stabilized for optical signals having different wavelengths.

In particular, it is possible to equalize the attenuation of different wavelengths by increasing the wavelength dependency of the MFD by adjusting the ratio of the axially inner core diameter to the core diameter by increasing the refractive index around the axially inner core portion relative to the peripheral portion of the core and by use of a dopant which attenuates signals having longer wavelength, for example, with a higher concentration within the inner core portion in which the refractive index is increased relative to the peripheral portion of the core to cancel the attenuation wavelength dependency of the dopant.

Further, the present invention provides an effective means of equalizing the attenuation of optical signals having a small difference in wavelength by use of a dopant which preferentially attenuates short wavelengths, at a higher concentration within the core portion (axially center portion) in which the refractive index is increased relative to the peripheral portion of the core.

Further, it is possible to increase the difference in attenuation due to the difference of wavelengths by increasing the wavelength dependency of the MFD by adjusting the ratio of the diameter of the axially inner portion of the core wherein the refractive index is increased relative to the peripheral portion of the core and the core diameter, by using a dopant which preferentially attenuates shorter wavelengths with a higher concentration within the axial central portion of the core wherein the refractive index is increased relative to the peripheral portion of the core and by increasing the wavelength dependency of attenuation of the dopant member.

Moreover, the present invention provides a very effective means for realizing an increase of attenuation of optical signals with different wavelengths, with minimal reduction of the MFD and minimal increase in the dopant concentration, by use of a dopant which preferentially attenuates longer wavelength optical signals, doped within the core wherein the refractive index is increased relative to the peripheral part of the core.

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ABSTRACT

An optical attenuator which provides almost the same degree of attenuation even when the difference in wavelength of two different kinds of input optical signals is small. Another optical attenuator is provided with a dopant concentration in a technically realizable range which increases the difference in optical attenuation of two different kinds of input optical signals. Almost the same degree of attenuation may be obtained even when the difference between wavelengths is small by canceling the wavelength dependency of attenuation of the dopant by raising the refractive index of an axially central portion of the core as compared to that of the peripheral portion of the core and by taking into account the type and area of the dopant and the ratio of the difference $\Delta 2$ between the refractive indexes of the cladding and the axial portion of the core and the difference $\Delta 1$ between the refractive index of the cladding and the refractive index of the peripheral portion, i.e., $\Delta 1/\Delta 2$. On the other hand, the difference of attenuation is increased while suppressing the concentration of dopant to the realizable range.

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DESCRIPTION

OPTICAL ATTENUATOR

TECHNICAL FIELD

The present invention relates to an optical attenuator and more specifically to an optical attenuator used for attenuating optical signals by a certain degree in the fields of optical communications, optical measurements, CATV system and the like.

BACKGROUND OF THE INVENTION

Hitherto, an optical attenuator comprising an optical fiber containing a certain optical attenuating dopant member has been widely known in general.

However, because the dopant member contained in this optical attenuator has a transmitted light attenuating characteristic that the attenuance varies depending on the wavelength of optical signal, i.e., it has a wavelength dependency, there has been known an optical attenuator which has lessened the wavelength dependency by obtaining almost the equal attenuance by adjusting a mode field diameter of an optical fiber and by limiting a dopant area with respect to the mode field diameter in order to obtain almost the equal attenuance in inputting optical signals of two different wavelengths of 1.3 µm (short wavelength) and 1.5 µm (long wavelength) for instance

("Kokai")

(Japanese Patent Laid-Open Nos. Hei. 8-136736 and Hei. 8-136737).

With the recent diversification of optical communications, it has come to be required to realize (created a demand for) an optical attenuator for (having) obtaining the equal optical attenuance (eliminating the wavelength dependency) even in a narrow wavelength range of 1300 mm ± 50 nm or 1550 ± 50 nm, for instance (example), or an optical attenuator whose wavelength dependency (in) of the optical attenua~~ce~~tion is increased even more in contrary (for) when optical signals of, for example, two different wavelengths of 1.3 µm (short wavelength) and 1.5 µm (long wavelength) are inputted.

However, although the optical attenuators disclosed in Japanese Patent Laid-Open ("Kokai") Nos. Hei. 8-136736 and Hei. 8-136737 are effective because they allow (give) almost the equal attenua~~ce to~~tion of be obtained when optical signals of two different wavelengths of 1.3 µm (short wavelength) and 1.5 µm (long wavelength) whose wavelengths are separated are inputted, they have had a (the) problem that it is (they are) unable to obtain (provide) the equal optical attenua~~ce~~tion (wavelength dependency is large) (merely) just by limiting the dopant area or by adjusting the mode field diameter when the difference of the wavelengths is small.

Meanwhile, when the optical signals of two different wavelengths of the short and long wavelengths are inputted, it is theoretically possible to realize the increase of the wavelength dependency of the optical attenua~~ce~~tion even more by

using a containing dopant which gives greater attenuat~~es~~ ion of the short wavelength optical signals more when ~~the wavelength of the optical signals is short so that it shows~~ with high concentration at part close to the axial core when the mode field is seen as a from the transverse section of the optical fiber or by using a containing dopant which gives greater attenuat~~es~~ ion of longwave the optical signals more ~~when the wavelength of the optical signals is long so that it~~ with shows higher concentration at a part close to the outer periphery of the optical fiber when the mode field is seen as a from the transverse section of the optical fiber in the optical attenuator disclosed in Japanese Patent Laid-Open ("Kokai") No. Hei. 8-136736.

It is also possible ~~to~~ theoretically to realize the equality one in Japanese Patent Laid-Open ("Kokai") No. Hei. 8-136737 by reversing the combination of the wavelength characteristics of the mode field diameter and the wavelength characteristics of the dopant member.

However, although the difference between the short wavelength and the long wavelength attenuation is increased becomes large by raising the dopant concentration and by limiting the doping area to a narrow range with respect to the mode field diameter, there has been a difficult problem that, because the doping concentration of the dopant member which can be contained in the optical fiber is limited, it is not possible unable to create a product having whose characteristics which are stable as an optical fiber when the concentration is too high and it is not unable to technologically possible to create ones whose doping area is very narrow.

optical fiber products

an optical fiber

SUMMARY OF THE INVENTION

The present invention has been devised in view of the above-described such difficult problems and has as its object, is firstly, to provide an optical attenuator which can equalize optical attenuance of optical signals having different wavelengths which are very close and, is secondly, to provide an optical attenuator which can maximize the difference of optical attenuance of the optical signals having different wavelengths in an ~~the state in which each characteristic of the~~ optical fiber with characteristics is stable and wherein the dopant concentration and doping area range are realistic by arranging the optical attenuator whose doping range may be realized with a x while suppressing the dopant concentration relatively low.

DISCLOSURE OF THE INVENTION

In order to achieve the above-mentioned objects, the present invention provides a single mode optical fiber, as an inventive optical attenuator having a core with a is constructed so that the refractive index of a at the center portion greater than part of a core of a single mode optical fiber is increased as compared to that of a the peripheral portion part of the core.

In this case, the wavelength dependency of the attenuation ~~attenuance~~ of transmitted light caused by the size of the mode field diameter is increased by adopting a distribution gradient one selected from ~~a~~ the group consisting of containing a gradient wherein graded-index type the refractive index rises continuously from the peripheral portion part to the center portion part, a parabolic shaped gradient, a triangular wave shaped gradient, a square wave shaped gradient and a trapezoidal wave shaped gradient as ~~the~~ a distribution of the refractive index of the core, "A"

By constructing the optical attenuator as described above, it is possible to widen the limited width of the dopant area for obtaining the required attenuating characteristics as much as possible and to minimize suppress the dopant concentration low utmost.

In one embodiment the An inventive optical attenuator contains dopant which provides greater attenua~~tes~~ion of longer wavelength transmitted light more when its wavelength is longer in a signal mode optical fiber and is constructed so that the dopant area is limited to the center part of the core and so that the refractive index at the center part of the core is greater raised than as compared to that of the peripheral part of the core.

In this case, the wavelength dependency of the attenua~~nce~~tion of transmitted light caused by the size of the mode field diameter is increased by adopting a gradient ~~one~~ selected from the ~~a~~ group consisting of ~~containing~~ "A" a ~~graded index type,~~ a parabolic shape, a gradient triangular wave shape, a gradient square wave shape and a gradient trapezoidal wave shape, a gradient as ~~the~~ distribution of refractive index of the dopant area,

By constructing the optical attenuator in this manner as described above, it is possible to obtain the equal attenua~~nce when~~tion of two input kinds of optical signals having different wavelengths which are short and whose difference is small (1300 nm ± 50 nm) are inputted.

In another embodiment the An inventive optical attenuator contain~~s~~ins dopant which provides greater attenua~~tes~~ion of shorter wavelength transmitted light more when its wavelength is shorter in a signal mode optical fiber and is constructed so that the dopant area is limited to the peripheral part of the core and so that the refractive index at the center part of the core

containing no dopant is greater than raised as compared to that of the peripheral part of the core.

In this embodiment also case, the wavelength dependency of the attenua~~nce~~tion of transmitted light caused by the size of the mode field diameter is increased by adopting a refractive index gradient one selected from the ~~a~~ group consisting of "A" containing a graded-index type, a parabolic shape, gradient triangular wave shaped gradient, a square wave shape gradient and a trapezoidal wave shape gradient, as the refractive index profile at the center part of the core where no dopant is contained.

By constructing the optical attenuator in this manner as described above, it is possible to obtain the equal attenua~~nce~~tion of when two kinds of input optical signals having different long wavelengths which are long and whose difference is small (1550 nm ± 50 nm) are inputted.

In still another embodiment an An inventive optical attenuator containing a dopant which preferentially attenuates shorter wavelength transmitted light more when its wavelength is shorter is ~~in~~ a signal mode optical fiber and is constructed so that the dopant area is limited to the center part of the core and so that the refractive index at the center part of the core containing no dopant is greater than raised as compared to that of the peripheral part of the core.

In this case, the wavelength dependency of the attenua~~nce~~tion of transmitted light caused by the size of the mode field diameter is increased by adopting a refractive index profile one selected from the ~~a~~ group consisting of "A" containing a graded-index type, a parabolic shape, gradient triangular wave shape, gradient a square wave shape gradient and a trapezoidal wave shape gradient as the distribution

of refractive index of the center part of the core containing no dopant.

By constructing the optical attenuator in the above manner ~~as described above~~, it is possible to obtain optical signals of two different wavelengths whose difference in ~~of~~ attenua~~nce~~tion of transmitted light caused by the difference of the wavelengths is maximized.

Another embodiment provides an ~~An inventive~~ optical attenuator contain~~s~~ing dopant which gives ~~attenuates~~ greater attenuation on transmitted light of longer wavelength ~~more when its wavelength is longer~~ in the form of a single mode optical fiber and ~~is~~ constructed so that the dopant area is limited to a ~~the~~ peripheral part of the core. ~~and~~ "A ~~so that the~~ graded-index type" is adopted as the refractive index profile of the dopant area to increase the wavelength dependency of attenua~~nce~~tion of transmitted light caused by the size of the mode field diameter.

In yet another embodiment an ~~An inventive~~ optical attenuator is constructed as a single mode optical fiber having a ~~so that the~~ greater refractive index at the center part of the core ~~is raised as compared to~~ than that of the peripheral part of the core due to incorporation of a ~~by containing~~ dopant whose transmitted light attenuating characteristics depend~~s~~ on the wavelength of optical signal input to ~~in~~ the optical fiber. ~~so that~~ The dopant concentration of the dopant area of the ~~a~~ single mode optical fiber is distributed non-uniformly to provide ~~by seeing~~ a mode field which substantially contributes to the transmission of optical signals in the radial direction, i.e. ~~in the~~ transverse ~~section~~ of the optical fiber.

In this case, the wavelength dependency of the attenua~~nce~~tion

of transmitted light caused by the size of the mode field diameter is increased by adopting ~~one~~ by 1 gradient selected from ~~a~~ the group ~~containing~~ consisting of "A" ~~a graded-index type~~, a parabolic shape ~~d~~ gradient, a triangular wave shaped gradient, a square wave shaped gradient and a trapezoidal wave shaped gradient. ~~as the distribution of refractive index of the dopant area.~~

By constructing the optical attenuator ~~as described above~~ in this manner, it is possible to obtain the required attenuating characteristics even when the dopant area is small and the dopant concentration ~~are~~ is ~~suppressed~~ low.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows the structure of one embodiment of an ~~inventive~~ optical attenuator according to the present invention, wherein the upper part of the figure shows an end face of the optical attenuator and the lower part shows a refractive index profile ~~seen from the side~~ thereof.

FIG. 2 shows ~~the~~ state of use in which the ~~inventive~~ optical attenuator of the present invention ~~is~~ disposed at the center of a ferrule.

FIGs. 3a and 3b are graphs showing the relationship between wavelength and loss ~~by~~ using various dopants ~~as parameters~~.

FIG. 4 is a graph showing the optical signal power distribution within the ~~inventive~~ optical attenuator of the present invention.

FIG. 5 is a graph showing the relationship between the ratio of difference of refractive index $\Delta 1/\Delta 2$, where $\Delta 1$ is the difference between the maximum refractive index ~~around the~~ of an axial ~~core~~ center portion of the core and the refractive index ~~around~~ in the ~~clad part~~ cladding

of [in] the [inventive] optical attenuator and Δ2 is the difference between the maximum refractive index in [around] the outer periphery al portion of the core and the refractive index of the cladding [clad part], and the difference of loss at 1.50 μm and 1.60 μm.

FIG. 6 is a graph showing the attenua~~nce~~tion with respect to wavelength when cobalt (Co) is doped in ~~at~~ the center portion [part] of the core of the [inventive] optical attenuator.

FIG. 7 shows the structure of another embodiment of the [inventive] optical attenuator of the present invention, wherein the upper part of the figure shows an end face of the optical attenuator and the lower part shows the refractive index profile [seen from the side thereof].

FIG. 8 is a graph showing the attenua~~nce~~tion with respect to wavelength when samarium Sm is doped in the whole core and [when] samarium Sm is doped only in an ~~the~~ axial portion of the core.

FIG. 9 is a graph showing the attenua~~nce~~tion with respect to wavelength when cobalt (Co) is doped in the whole core and [when] cobalt (Co) is doped only in the outer periphe~~ry~~al portion of the core.

BRIEF DESCRIPTION OF REFERENCE NUMERALS

5, 5' Single Mode Optical Fiber

6, 6' Core

6a, 6a' Center portion [Part] of Core [(Center Core)]
[(Part] Portion close to the [axial] core axis [in center area])

6b, 6b' Outer Periphery portion of Core [(Outer Core)]

portion the
(Part close to outer periphery of core)

7, 7' Dopant Area

9, 9' Mode Field

DESCRIPTION OF THE PREFERRED EMBODIMENTS

BEST MODE FOR CARRYING OUT THE INVENTION

Preferred embodiments of an inventive optical attenuator will be explained below with reference in accordance to the drawings.

FIG. 1 is a section view showing the structure of an the ~~inventive optical attenuator, wherein the upper part of the figure shows an end face of the optical attenuator and the lower part shows a refractive index profile seen from the side thereof.~~ This optical fiber 5 which is used by disposing tion at the center of a ferrule 2 by a method as shown in FIG. 2, for example. That is, in use it is used so that it receives an optical signal at from one end thereof and it outputs the signal from the other end after attenuating the optical signal by a certain degree. To this end a dopant Dopant for attenuating the optical signal is incorporated into doped in the optical fiber 5 to that end.

In this embodiment Here, a graded-index type (its refractive index increases continuously from the outer peripheral part to the center part) is adopted as a refractive index profile at the center portion part 6a (center core) close to the axis axial core of the core 6 of the inventive optical attenuator and a high concentration of ~~te~~ dopant is contained doped within this area 7. The dopant area 7 is hatched in the figure.

Because a core diameter $2a_2$ is very small in the single mode fiber, energy of the optical signal propagates centering on the

a portion

cladding

core 6 while actually overflowing even to part of the clad 8 at the outer periphery of the core 6. The range in which the larger portion part of the energy is contained is a mode field 9 portion part which substantially contributes to the transmission of the optical signals and may be found qualitatively by using Equation 1, as a method explained later for both ~~by using Equation 1. It is noted that it is the same even in~~ the step-index type fiber and or in the graded-index type fiber. In the optical fiber 5 shown in FIG. 1, the diameter of the mode field 9 is denoted as 2ω, the diameter of the dopant area 7 as $2a_1$ and the diameter of the core 6 as $2a_2$. The difference between the maximum refractive index around the axial portion core of the core 6 and the refractive index of the cladding clad 8 part is denoted as $\Delta 2$ and the difference between the maximum refractive index of the outer peripheral portion part 6b (outer core) of the core 6 and the refractive index of the cladding clad 8 part as $\Delta 1$.

Use of Such dopants contained in the optical fiber 5 to attenuate the optical signals will now be explained here. FIGs. 3a and 3b are graphs showing the relationship between wavelength and loss for of various dopants. The horizontal vertical axis of the graph represents the wavelength in nanometers [nm] and the vertical axis represents the optical attenua~~nce~~tion in [dB/km]. A transition metal or rare-earth metal dopant is normally used in optical fibers for communications. They may be used singly or in combinations of by mixing one or two or more. respectively. In FIG. 3a, (1) denotes the characteristics of manganese (Mn), (2) nickel (Ni), (3) chrome (Cr), (4) vanadium (V), (5)

cobalt (Co), (6) iron (Fe), and (7) copper (Cu). In FIG. 3b, (8) represents the characteristics of samarium (Sm) and (9) thulium (Tm).

The first embodiment of the ~~inventive~~ optical attenuator of the present invention uses ~~the~~ a dopant which attenuates more transmitted light when the wavelength of the optical signal is longer. When the wavelength to be used in this optical attenuator is around 1.5 μm to 1.6 μm for example, ~~it~~ as can be seen from FIG. 3a, ~~that~~ cobalt (Co) is ~~suited~~ suitable as the dopant.

FIG. 4 shows the optical signal power distribution when cobalt Co is used as the dopant and the dopant is contained in the area as shown in FIG. 1. The vertical axis of FIG. 4 represents the output power and the horizontal axis represents the position ~~of~~ in the fiber in the radial direction. K1 in FIG. 4 is power distribution in the radial direction when an optical signal of a wavelength of 1.5 μm is transmitted through the optical fiber. A curve K2 represents the power distribution of an optical signal of 1.6 μm.

Table 1 shows the difference of mode field diameter (hereinafter referred to as "MFD") corresponding to the respective wavelengths λ1 and λ2 in each fiber when the respective wavelengths λ1 = 1.50 μm and λ2 = 1.60 μm are inputted to the fiber having the structure of the first embodiment ~~of the inventive optical attenuator~~ as shown in FIG. 4 and to the normal step index type fiber.

Table 1

	Difference (μm) of mode field diameter of 1.50 μm and 1.60 μm
First Embodiment	0.52
Step index	0.25

This shows that the difference of MFD of the inventive fiber caused by the difference of wavelengths wavelenegths is large (wavelength dependency is large).

Then, When cobalt (Co) is contained concentrated ly in to the axial portion core part of the core, the longer the wavelength of a signal, the less the the portion rate of the part influenced by the attenuation seen from of the whole signal energy becomes.

This means that it cancels the wavelength dependency of the optical attenuance of the dopant is cancelled member.

As a result, the optical signals of short and long wavelengths, whose difference of wavelength is small, attenuate to ~~in~~ the same degree in this attenuator as a whole.

In case of the conventional step index type fiber, the concentration of dopant has is become high and it has causes ~~caused~~ a serious production problem as a result when it is designed so as to show the same degree of attenuation is with the first embodiment described above, because the dopant area of cobalt Co must be narrowed because the wavelength dependency of the optical attenuation ~~attenuance~~ of the MFD is small.

A concrete example will be shown below using with reference to

and 2 is given below is used for calculation of

Equations 1. Equation 1 shows methods for calculating the

tion and equation 2 is used for calculation of

attenua~~nce~~ α of the optical fiber and the mode field diameter

ω.

Expression 1

Attenua~~nce~~tion α	$$\alpha = \frac{\int \alpha_{Co} A(r) P(r) r dr}{\int P(r) r dr} \quad \text{... Equation (1)}$$ α: attenua~~nce~~tion per 1 cm r: coordinate of fiber in radial direction A(r): concentration of Co in radial direction αCo: coefficient of absorbency of Co $\lambda = 1.50\ \mu m \rightarrow 5.19 \times 10^{-3}$ dB/cm·ppm^{-1} $\lambda = 1.60\ \mu m \rightarrow 5.95 \times 10^{-3}$ dB/cm·ppm^{-1} P(r): optical power distribution in radial direction
Mode Field Diameter ω	$$2\omega = 2\left[2\frac{\int P^2(r) r^3 dr}{\int P^2(r) r dr}\right]^{\frac{1}{2}} \quad \text{... Equation (2)}$$ P(r): optical power distribution in radial direction r: coordinate of fiber in radial direction

As shown in Equation (1), the attenua~~nce~~tion α of the optical signal in the optical fiber may be found from the power distribution P(r) of the optical signal in the radial direction and the distribution of concentration of cobalt, i.e., the dopant. The mode field diameter ω may be found from Equation (2).

The ratio (a1/a2) of the area in which the graded-index type is adopted as the profile containing cobalt (Co) to the core diameter approaches to the step index type when it is too large or too small and the wavelength dependency of the mode field diameter ω approaches to the step index type. When the ratio (a1/a2) is small, although the wavelength dependency of the attenua~~nce~~tion α becomes small because the dopant area of cobalt (Co)

becomes small, even when the wavelength dependency of the mode field diameter ω is small, there have been problems such as an increase of the doped amount of cobalt dopant Co and an increase of processing steps. Here, ~~a~~ the result of using $a1/a2 = 0.5$ is shown.

FIG. 5 is a graph representing the ratio of difference of refractive index $\Delta 1/\Delta 2$ by the horizontal axis and the difference of loss (attenua~~nce~~tion) at 1.50 μm and 1.60 μm when the attenua~~nce~~tion at 1.55 μm is 10 dB by the vertical axis. It can be seen from FIG. 5 that the greater the ratio $\Delta 1/\Delta 2$, the wider the difference of the attenua~~nce~~tion at 1.50 μm and 1.60 μm becomes. The wavelength dependency of attenua~~nce~~tion of the dopant member may be cancelled by this value.

It is noted that Table 2 shows the structural characteristics of the fiber with of $\Delta 1/\Delta 2 = 0.75$, whose wavelength dependency is small, as shown in FIG. 5. $\Delta 1/\Delta 2$ is not 0.35 because it represents a shows the practical fiber structure in which bending loss and others are taken into account.

FIG. 6 is a graph showing the attenua~~nce~~tion with respect to the wavelength of the fiber in Table 2. The wavelength dependency is lessened by doping cobalt dopant in Co to the center portion part of the core of the optical attenuator and by adopting the graded-index type as the profile.

Table 2

	Core	a1/a2	$\Delta 1/\Delta 2$	MFD	MFD

	Diameter			(1.50 μm)	(1.60 μm)
Embodiment	7.4 μm	0.5	0.5	9.15	9.67
Step-Index	9.5 μm	0.5	0.5	9.26	9.51

This sample has been set so that the whole distribution of concentration of cobalt becomes fixed within the range in which cobalt Co is contained. The attenua~~nce~~ tion of the optical fiber has been set so that it to becomes 10 dB/m. As a result, $\Delta1/\Delta2 = 0.35$ and the wavelength dependency was eliminated when $a1/a2 = 0.5$. A The wavelength independent optical attenuator may be obtained by increasing $\Delta1/\Delta2$ when $a1/a2$ becomes large and by decreasing $\Delta1/\Delta2$ when $a1/a2$ becomes small.

The dopant which attenuates transmitted light more when the wavelength of the optical signal is longer is has been used in at the center portion part 6a ~~(center core) close to the axial core~~ of the core 6 of the optical fiber 5 in the first embodiment described above. In the alternative Meanwhile, dopant which attenuates transmitted light more when the wavelength of the optical signal is shorter may be also used by changing the area where the dopant is doped. For instance, vanadium V of (4) and the like are shown may be cited in the example of FIG. 3a.

FIG. 7 shows a second embodiment of the inventive optical attenuator using a the dopant which attenuates transmitted light more when the wavelength of the optical signal is shorter. In the second embodiment, a dopant-containing area 7' is created by containing the dopant which preferentially attenuates the transmitted light

shorter wavelength

more [when] the wavelength of the optical signal is shorter [at] in a peripheral [part] portion 6b [(outer core)] of [a] core 6' [except of the diameter] in which the refractive index profile is set as the graded-index type. In this case, the longer the wavelength of the optical signal whose power distribution extends in the radial direction of the optical fiber 5', the more it is influenced by the dopant.

Thus, the optical attenuation [~~characteristics~~ of ~~the~~ ~~inventive optical attenuator to~~] of the optical signal of wavelength within a certain range may be almost equalized by increasing the wavelength dependency of the mode fields 9 and 9', which substantially contribute to the transmission of optical signal of the single mode optical fiber, by controlling the refractive index profile, by [adequately] selecti~~ng~~on of the distribution of concentration of dopant [by seeing] within the transverse section of the cores 6 and 6' of the optical fibers 5 and 5' and by using [the] a dopant whose transmitted light attenuating characteristics depend~~s~~ on the wavelength of the optical signal. It is noted that although the dopant is doped only [to] in the axial [core part] portion 6a of the core 6 or [to] in the peripheral [part] portion 6b of the core 6 in the embodiments described above, it is possible to [apply] appropriately distribut~~ion~~e [of] concentration. Also, it is not necessary to obtain [the] uniform characteristics [to] for all wavelengths of optical signals and it is possible to set a [containing] concentration range so that a certain attenua~~nce~~tion may be obtained [per each range] for optical signals of several ranges.

The first and second embodiments have the structure effective in obtaining provide almost the same attenua~~nce~~tion to one having the small difference of wavelengths of optical signals of two different kinds of wavelengths to be inputted.

Next, In a third embodiment of the inventive optical attenuator will be explained. of the present invention, the

¶ The refractive index profile around the axial core portion of the core of the single mode fiber is the same with those as that of the first and second embodiments described above. However, the third embodiment

¶ The part which is different is in that the wavelength dependency of the MFD is increased by doping a member use of a dopant which attenuates transmitted light when the wavelength is short, e.g. samarium Sm shown by (8) in FIG. 3b, ~~as the dopant member to be~~ doped in the axial portion of the core part and by adjusting the ratio between of the diameter at the part of the axially central portion of the core where the refractive index of the axial core part is set as the graded-index type and the core diameter.

FIG. 8 is a graph showing the attenua~~nce~~tion with respect to wavelength when samarium Sm is doped in the whole core and when samarium Sm is doped only in the axial central portion of the core. It can be seen from the graph that the attenua~~nce~~tion is greater when samarium is doped only in to the axial portion of the core between i.e. 1530 nm to 1550 nm.

The shorter the wavelength, the greater the optical signal is attenuate~~d~~ when two kinds of optical signals having different wavelengths are inputted. Further, a greater attenua~~nce~~tion may be obtained without reducing the center core diameter more than one required

and without increasing the dopant concentration [by constructing as described above.]

third embodiment

Accordingly, this [construction] is very effective in increasing the difference of attenua~~nce~~tion of those [optical signals by inputting the] two kinds of optical signals having different wavelengths.

In [Next,] a fourth embodiment of the invention [inventive optical attenuator will be explained.]

¶ The refractive index profile around the axial core of the core of the single mode fiber is the same as [with] those of the first and second embodiments described above. However, this fourth embodiment

¶ in [What] is different [is] that the wavelength dependency of the MFD is increased by use of a dopant [doping the member] which attenuates transmitted light more when its wavelength is longer, e.g., cobalt Co, in [at] the portion [part] of the core surrounding the axial center portion [around the diameter] where the refractive index profile [of the axial core part] is set as the graded-index type and by adjusting the ratio of the diameter of the portion having a [part where the] refractive index of [the axial core part is set as] the graded-index type (axial center portion) and the core diameter.

FIG. 9 is a graph showing the attenua~~nce~~tion relative [with respect] to wavelength when cobalt Co is doped throughout [to] the whole core and when cobalt Co is doped only in an [to the] outer peripher~~y~~al portion of the core. It can be seen from the figure that the attenua~~nce of one in which~~tion where Co is doped only in [to] the outer peripher~~y~~al portion of the core is greater between 1560 nm to 1570 nm.

The longer the wavelength, the greater the optical signal is attenuate~~s~~d when two kinds of optical signals having different wavelengths are inputted. Further a great^er^ attenua~~nce~~tion may be obtained without increasing the dopant concentration more than what is required by constructing as described above.

Accordingly, this fourth embodiment construction is very effective in increasing the difference ~~of~~ in attenua~~nce~~tion of those optical signals by inputting the two kinds of optical signals having different wavelengths.

INDUSTRIAL APPLICABILITY

As it is apparent from the above description, according to the present invention inventive optical attenuator, it is possible to fix the optical attenua~~nce~~tion for optical signals having different wavelengths which are very close with a practical by arranging the optical attenuator which allows the doping range in which to be realized while suppressing the dopant concentration is relatively low.

Further, according to the present invention ~~inventive optical attenuator~~, it is possible to increase the difference ~~of~~ in optical attenua~~nce~~tion as much as possible with a practical while having the realistic dopant concentration and a doping area range in the state in which each characteristic of the optical fiber is stabilized for optical signals having different wavelengths.

In particular, it is possible to equalize the attenua~~nce~~tion of different wavelengths by increasing the wavelength dependency

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longer wavelength more, for example, concentrat~~edly~~ within the portion
diameter in which the refractive index around the axial core of
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core to cancel the attenua~~nce~~ wavelength dependency of the dopant
member.

the present invention provides an of
Further, it becomes effective means in equalizing the
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portion (axially center portion)
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Further
Still more, it is possible to increase the difference ~~of~~ in
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the wavelength dependency of the MFD by adjusting the ratio of
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peripheral part of the core and the core diameter, by doping the using a
preferentially shorter
dopant member which attenuates more when the wavelengths is short
with a higher ion axial central portion ~~of~~ the core wherein
concentrat~~edly~~ within the ~~diameter in which~~ the refractive index
relative
at the center part within the core is increased as compared to

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the peripheral part of the core and by increasing the wavelength

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dependency of attenua~~nce~~ of the dopant member.

The present invention provides a an

Moreover, it becomes very effective means ~~in~~ for realizing the

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part of the core around the axial core of the core is increased

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optical signals, doped

ABSTRACT

There is provided an optical attenuator which provides almost the same degree of attenua~~nce~~tion even when the difference ~~of~~ in wavelength of two different kinds of input optical signals is small. ~~Further, an~~ Another optical attenuator is provided realized with a dopant concentration in a the technically realizable range which in increas~~ing~~es the difference ~~of~~ in optical attenua~~nce~~tion of two different kinds of input optical signals.

Note → Almost Firstly, almost the same degree of attenua~~nce~~tion may be obtained even when the difference ~~of~~ between wavelengths is small by canceling the wavelength dependency of attenua~~nce~~tion of the dopant ~~by increasing the wavelength dependency of the mode field~~ by raising the refractive index of an optical fiber 5 around an axial central portion of the ~~core 6a within a~~ core 6 area as compared to that of the a peripheral portion part 6b of the core and by taking into account the type and area of the dopant member to be doped and the ratio of the difference Δ2 between the refractive indexes of the cladding clad and the axial portion of the core and the difference Δ1 between the refractive index of the cladding and the refractive index of the peripheral portion the other part, i.e., Δ1/Δ2. On the other hand Secondly, the difference of attenuation attenuances is increased while suppressing the concentration of dopant to the realizable range.